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ANNUAL REPORT

To the Division of Atmospheric Water Resources Management Bureau of Reclamation U.S. Department of the Interior

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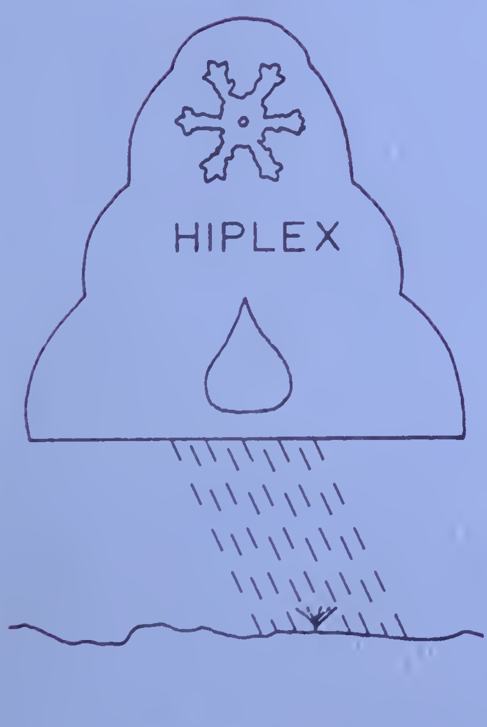
OCTOBER, 1975



DEPARTMENT OF

NATURAL RESOURCES AND CONSERVATION

Box 1350
Miles City, Montana 59301

ANNUAL REPORT FOR THE PERIOD

Jan. 1, 1975 through Sept. 15, 1975

to the

DIVISION OF ATMOSPHERIC WATER RESOURCES MANAGEMENT, BUREAU OF RECLAMATION, U.S. DEPARTMENT OF THE INTERIOR

by

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State of Montana

October, 1975

Acknowledgment

We wish to thank NCAR for the use of their Belfort recording raingages used in this year's field program. We also thank the farmers and ranchers of the area whose cooperation in granting access permission made the field program possible.

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I. INTRODUCTION

The HIgh PLains EXperiment (HIPLEX) is a cooperative project coordinated by the Bureau of Reclamation with participants from various groups and government agencies. The goal of HIPLEX, as a part of the Bureau of Reclamation's Project Skywater, is to develop an effective weather modification technology. This technology must be scientifically and socially acceptable to serve a portion of the nation's water resource needs. The objective of HIPLEX is to develop this technology for the High Plains.

Three experimental sites were chosen for HIPLEX. These are Miles City, Montana; Colby-Goodland, Kansas; Big Spring, Texas. The State of Montana's role in HIPLEX during the first field season (1975) was to establish and monitor surface meteorological and ecological data collection systems at the primary experimental site (Miles City, Montana). Within this framework the State of Montana established, tested, and collected data from surface rainfall sites and ecological monitoring sites. In addition to surface network installation and maintenance considerable effort was expended in the installation and development of new rainfall and ecological data collection systems.

II. FACILITY DEVELOPMENT

A. Surface Rainfall Networks

Surface rainfall data were collected near the experimental site in the summer of 1975 for the following purposes:

(1) To generate Z-R relations in conjunction with two C-band radars located at the experimental site and to provide various rainfall statistics needed for designing the future randomized seeding experiment;

(2) To investigate errors related to attenuation in the C-band radar measurement of rainfall;

(3) To establish the reliability of two newly designed raingage systems (ERTS and memory type) under field conditions;

(4) To determine rainfall catch as a function of height above ground for the types of gages used.

Eight types of raingages were employed to accomplish these objectives. A list of these raingages, their reliability, resolution, and use is shown in Table 1.

Table 1. The types of raingages used during the 1975 field season showing their reliability, resolution, and use.

Raingage Type	Accuracy (inch)	Resolution (min)	Use
Belfort Weighing	±.02	15	Cluster Network Line Network Rainfall Catch Experiment
ERTS	±.01	15	Radio-Telemetry Network
Memory	±.01	15	Radio-Telemetry Network
Forestry	±.02	non-recording	Rainfall Catch Experiment
Pit	±.01	15	Rainfall Catch Experiment
Belfort Pit	±.02	15	Rainfall Catch Experiment
Wedge	±.01	non-recording	Rainfall Catch Experiment
Cannister	±.05	non-recording	Rainfall Catch Experiment

The primary raingage used was the conventional Belfort weighing type. All 80 Belfort raingages used were loaned to the State of Montana by the National Center for Atmospheric Research (NCAR).

Cluster Network. To satisfy the first objective of the rainfall networks, a test area of 800 km^2 with a gage density of 15 km^2/gage was chosen. The selection of the Cluster Network site was based on 5 criteria; (1) a dense surface raingage network was needed at the mid-range of the radar to derive reliable Z-R relations; (2) data from a collocated Radio-Telemetry Network were to be transmitted to a centrally located "data central." Because of the "line of sight" telemetry requirement of this system fairly flat topography within the Cluster Network was essential; (3) a radiosonde launch point was located at each corner of a trapezium east-south east of the experimental site. For mesoscale investigations it was best to have the Cluster Network near the center of this trapezium; (4) it was desired to place the Cluster Network where mean summer rainfall was relatively high because such an area would maximize radar calibration test cases; (5) finally, an easily accessible area was desired.

The positions of the 55 conventional Belfort raingages in the Cluster Network are shown in Fig. 1a. Each site was fenced to provide protection from livestock. Figure 1b is a view of site 6A facing south. It shows a typical site configuration and location in the Cluster Network.

A conventional Belfort raingage was placed within each site comprising the Cluster Network and calibrated during the period 1-15 May 1975. As demonstrated in Fig. 1b, each raingage was mounted on a level stand with its orifice 3 feet above ground. Typically, a raingage was placed within the east central portion of each monitoring site.

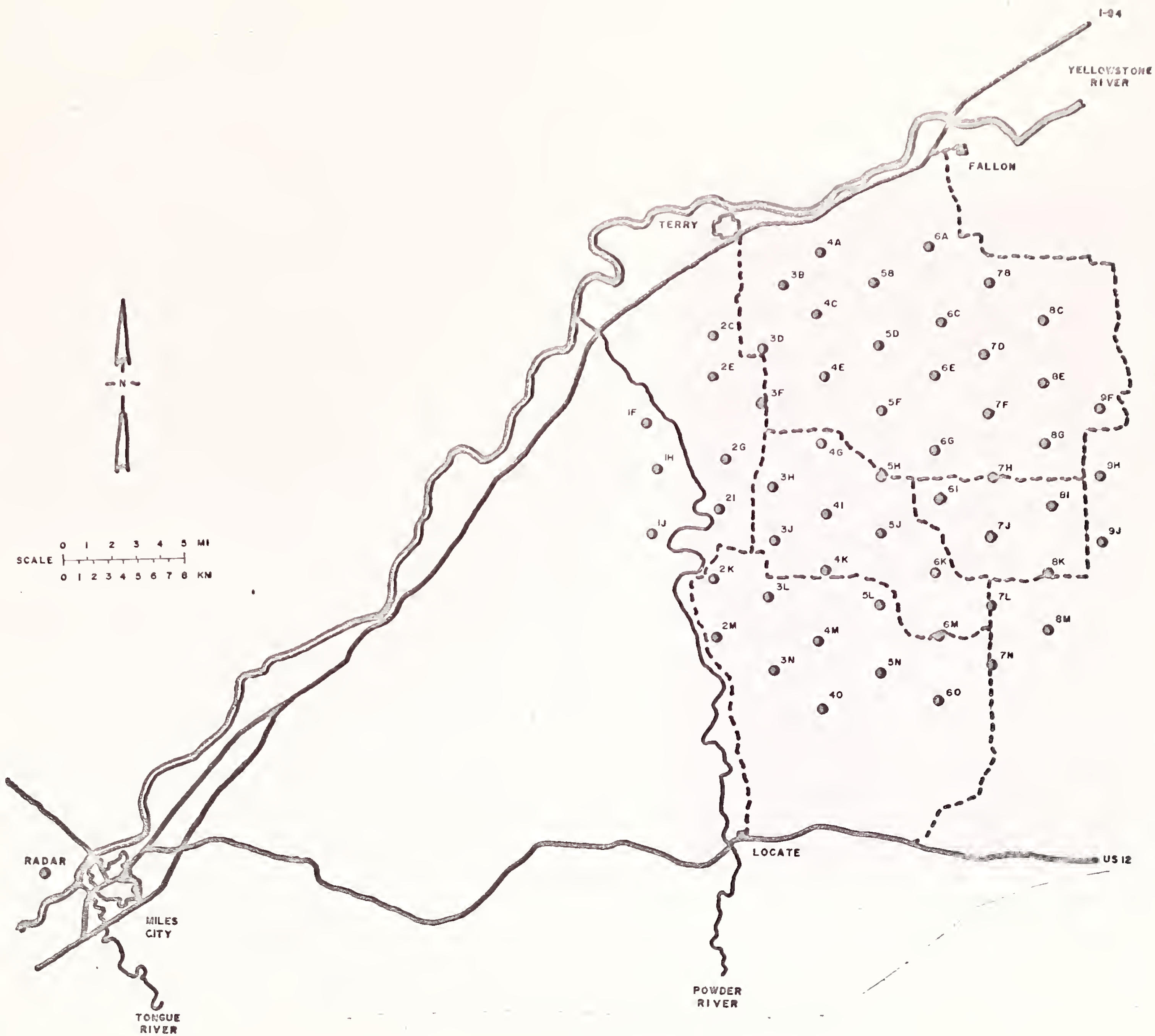

Figure 1a. The location and alphanumeric identification of the 55 raingage sites in the HIPLEX Cluster Network.

Figure 1b. South facing view of raingage site 6A

The recording mechanism in every Belfort gage was configured so that the chart drum rotated once every 24 hours. Service technicians visited each raingage a minimum of once per week. At these times routine service and maintenance operations were performed. In the event a malfunction was discovered that raingage was repaired and checked again the day after repair. To expedite data reduction a small amount of water was used to charge the weighing mechanism in each Belfort raingage during servicing. Continuous evaporation of this water provided a convenient separation between rainfall traces from day to day. With this servicing scheme precise rainfall measurements were provided at 15 minute intervals throughout the field season.

To improve data quality a recalibration of all Cluster Network raingages was performed during the period 1-15 July 1975. Then, a final

calibration check was made before removal of the raingages from the Cluster Network. All 55 raingages of the Cluster Network continued to gather rainfall data until 15 September 1975.

Considerable data reduction work was needed to provide rainfall data from the Cluster Network in a form useable to scientists. Rainfall values were extracted at 15 minute intervals from the original raingage charts on two separate occasions. Each set of initial readings were then computerized. Quality control and error elimination procedures were performed with the aid of a computer. Then appropriate calibration adjustments were made to the data and a final form of the rainfall data was stored on magnetic tape. On 15 September 1975 approximately 10% of the Cluster Network rainfall data resided on magnetic tape in final form. The remaining 90% of the 1975 rainfall data were being systematically computerized, checked for accuracy, and placed in a useable form.

Hail aloft produces a much higher radar reflectivity than rainfall and, thus, an abnormally high radar rainfall estimate. Thus, it was desirable to detect the occasions when hail occurred at the Cluster Network sites. To yield a simple yes/no answer about the occurrence of hail within the Cluster Network, styrofoam hail pads with aluminum foil covers were deployed. A 25 cm x 25 cm hail pad was placed at ground level in all Cluster Network sites during early July 1975. Plans were made to change hail pads after each hail occurrence. During the period July-September only 2 hailpads received any hailfall.

<u>Line Network</u>. To satisfy the second objective of the rainfall networks (to investigate errors related to attenuation in the C-band radar measurement of rainfall) a line comprised of 16 Belfort weighing raingages was

chosen. This line of raingages extended along an azimuth of 66 degrees true from the experimental site for 108 km. Thus, a spacing of approximately 7 km/gage was provided.

The selection of the Line Network location was based on 5 criteria; (1) rainfall data along a radar azimuth offer an attractive means to examine attenuation related errors in rainfall measurement by radar; (2) rainfall data along a line offer a ready means of calculating the spatial variation of correlation coefficients among gages. This information will be useful in determining gage densities required for future wide area seeding experiments; (3) it was desireable to use some of the Cluster Network gages as part of the line to minimize the total number of gages needed; (4) again, areas where radar, radiosonde (mesoscale studies), and precipitation data overlap were desired; (5) finally, priority was given to areas with higher than average mean summer precipitation.

The positions of the 16 conventional Belfort raingages in the Line Network and their relation to the Cluster Network are shown in Fig. 2a. As before, each site was fenced to provide protection from livestock. Figure 2b is a view of site 18 facing south. It shows a typical site configuration and location in the Line Network.

In studying the effects of radar attenuation with distance, the knowledge of hailfall is important. Thus, hailpads identical to those of the Cluster Network were deployed at each Line Network site. During the period July-September no hail was detected at any Line Network site.

It was necessary to fly research aircraft over and along the Line Network during rainfall periods for sampling purposes. In such cases a visual identification of alternate raingage sites in the Line Network was necessary. Florescent panels were placed within alternate raingage

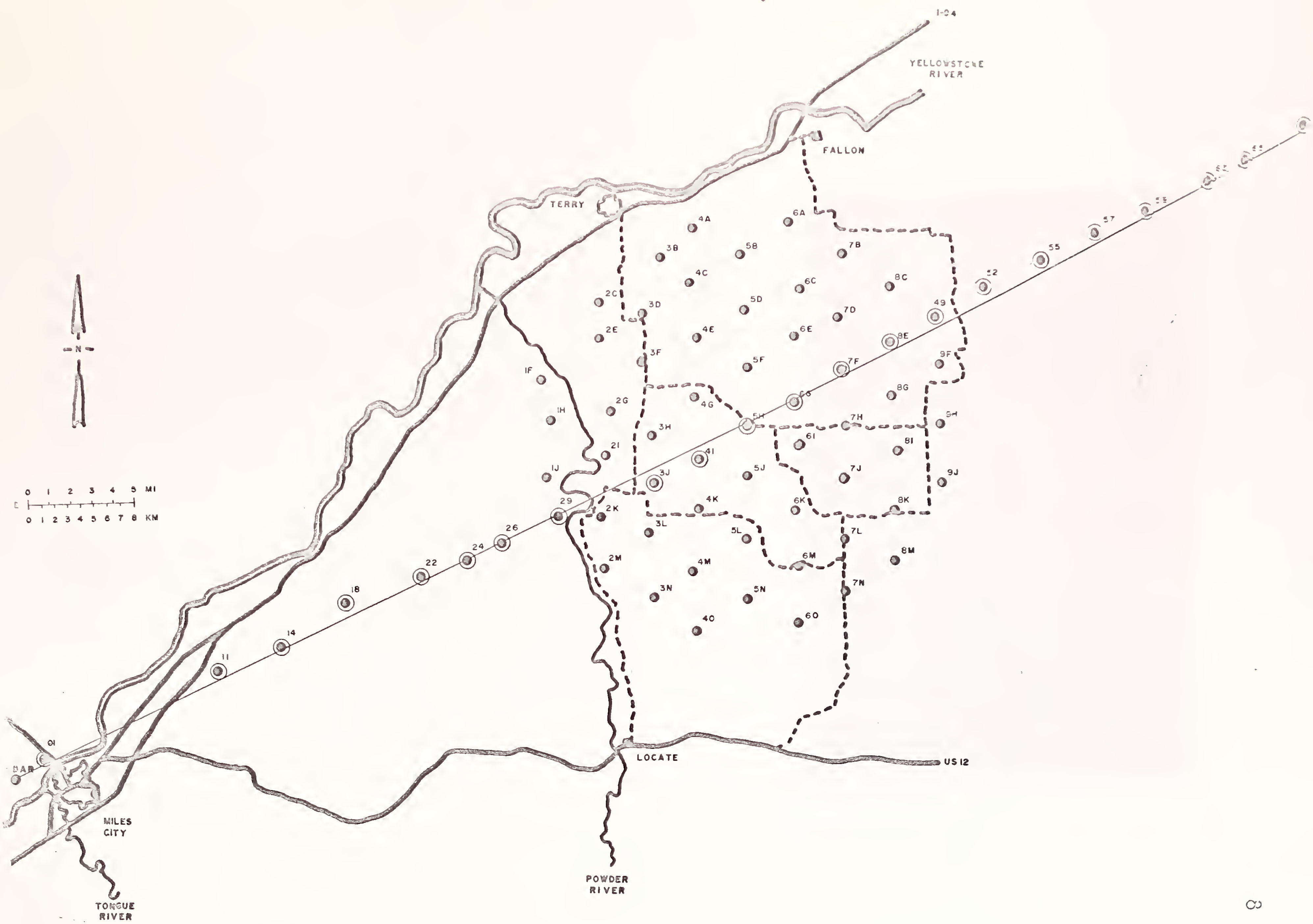

Figure 2a. The location and alphanumeric identification of the 16 raingage sites in the HIPLEX Line Network. The relation between the Line Network and Cluster Network is also shown.

Figure 2b. South facing view of raingage site 18.

sites in the Line Network to enhance their visibility. Fig. 3a-b is a) a view looking east toward site 18 and b) a view of site 18 from overhead. Both pictures were taken from 4000 ft, MSL (1500 ft, AGL). Even in hazy or rainy periods sites in the Line Network equipped with florescent panels remained highly visible.

The Belfort raingages used in the Line Network were installed, serviced and calibrated in a similar manner to those of the Cluster Network. Rainfall data reduction work from the Line Network was performed identically to that of the Cluster Network. This provided good quality rainfall data with 15 minute resolution (consistent with that of the Cluster Network). On 15 September 1975 roughly 10% of the Line Network rainfall data resided on magnetic tape in a useable form. The remaining 90% of the 1975 rainfall data was being systematically computerized, checked for accuracy, and placed in a useable form.

Figure 3a. East facing view of raingage site 18 from 4000 ft, MSL

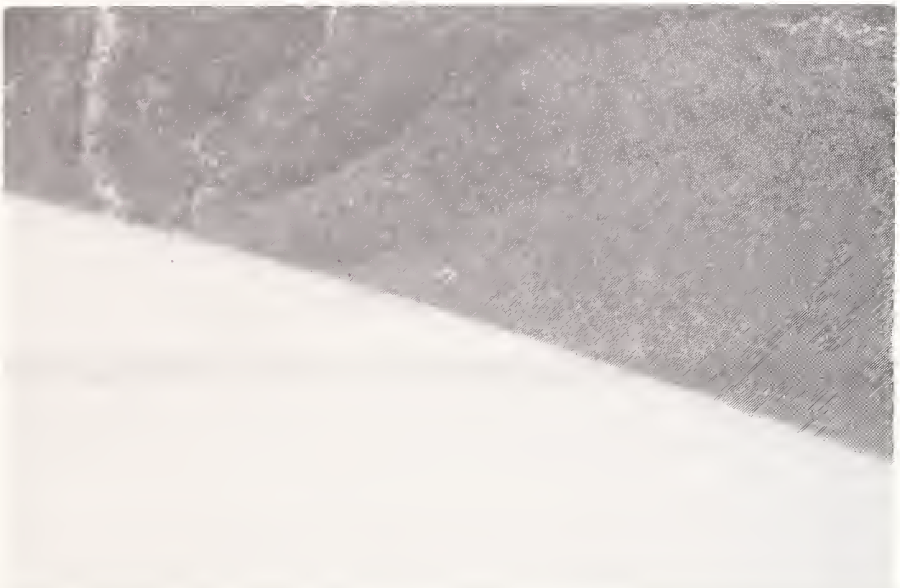

Figure 3b. View of raingage site 18 from overhead at 4000 ft, MSL. Note the visibility of the florescent panels within the site.

Radio-Telemetry Network. To satisfy the third objective of the rainfall networks (to establish the reliability of two newly designed raingage systems under field conditions) it was planned to collocate a radio-telemetry gage with each Belfort gage in the Cluster Network and Line Network. Two types of radio-telemetry raingages were to be deployed at the experimental site during 1975. The first system (the "ERTS Network") transmits rainfall data to a "data central." The data central is then interrogated by an Earth Resources and Technology Satellite (ERTS) when the satellite is overhead. The second system stores rainfall data at each raingage station. An aircraft flying overhead then interrogates each "memory gage" on alternate days to obtain its rainfall data.

Original plans called for placing an ERTS gage at each site in the Cluster Network and a memory gage at each site in the Line Network. Delivery of these raingages was expected by 1 July 1975. Delays in manufacture and testing resulted in delivery of the ERTS raingages by 15 August 1975 and no delivery of the memory raingages.

Installation of the 50 ERTS raingages available was completed by 1 September 1975. Fig. 4 shows an ERTS raingage at site 6A collocated with the Belfort raingage of the Cluster Network. Fig. 5 shows a closeup of the ERTS raingage at site 6A. Each ERTS raingage was placed approximately in the center of a Cluster Network site with its orifice 24 in above ground.

Quality control procedures and initial checks of the ERTS raingage system revealed several hardware problems. These resulted in further delays. No meaningful data was obtained from the ERTS raingage system before 15 September 1975. Plans were made to collect data with any functional ERTS raingages and collocated Cluster Network raingages until after 1 October 1975.

Figure 4. South facing view of raingage site 6A with a Belfort and radio-telemeter raingage installed.

Figure 5. The radio-telemeter raingage at site 6A.

Rainfall Catch Experiment. To satisfy the fourth objective of the rainfall networks (to determine rainfall catch as a function of height above ground for the types of gages used) a test plot with 14 raingages was constructed at the Miles City Airport. Table II shows the raingage type, quantity, and orifice height above ground used in this Rainfall Catch Experiment.

Table II. The raingage type, quantity, and orifice height above ground used in the Rainfall Catch Experiment.

Raingage Type	Raingage Quantity	Raingage Orifice Height Above Ground (inches)
Belfort Weighing	3	2 - 36 1 - 2
Forestry	4	2 - 15 2 - 57
Wedge Gage	4	2 - 57 2 - 15
Cannister Gage	2	2 - 15
Pit Gage	1	1 - at surface

Two raingages in the Rainfall Catch Experiment had their orifice at or near ground level. These were planned as controls for the experiment. The rest of the raingages had their orifice either at 15 in above ground (the planned height of the orifice on the radio-telemetry raingages), 36 in above ground (the height of the orifice on the Cluster Network and Line Network gages) or 57 in above ground (in order to provide a third data point in the generation of orifice height-rainfall catch curves). Figure 6a-d shows; a) an overall view of the Rainfall Catch Experiment

site; b) a view of the collection area of the pit gage used as a control for the experiment; c) one of the wedge gages with orifice at 15 in above ground; d) one of the forestry gages with orifice at 15 in above ground.

The Rainfall Catch Experiment contained 4 recording and 10 non-recording raingages. To obtain reasonable data it was necessary to measure the total precipitation after each rainfall episode. During the field season more than 20 rainfall episodes were sampled.

In addition to acquiring rainfall estimates at several heights it was desired to obtain wind speed measurements at different heights above ground. These data would then be used to refine estimates of rainfall catch as a function of orifice height above ground. Two cup anemometers were installed at the Rainfall Catch Experiment site in early June. They were configured to continuously measure wind speed at 15 in and 57 in above ground.

Data from the Rainfall Catch Experiment will be used to develop relationships between rainfall catch, orifice height, gage type, and wind speed. By developing empirical relations between rainfall catch at the surface and at selected heights two purposes will be served. First, rainfall catch from collocated network raingages with different orifice heights can be adjusted using empirically developed relations to simulate identical orifice height. Second, the actual rainfall at the surface can be projected from rainfall measurements made above ground. Previous studies, including Gold (1922), Kurtyka (1953), Neff (1966), Smallshaw (1953) and Storey and Hamilton (1943) indicate a 10-20% negative error in rainfall catch is not uncommon when comparing rainfall catch at standard height (36 in) to surface rainfall catch.

Figure 6a. A view of the Rainfall Catch Experiment site.

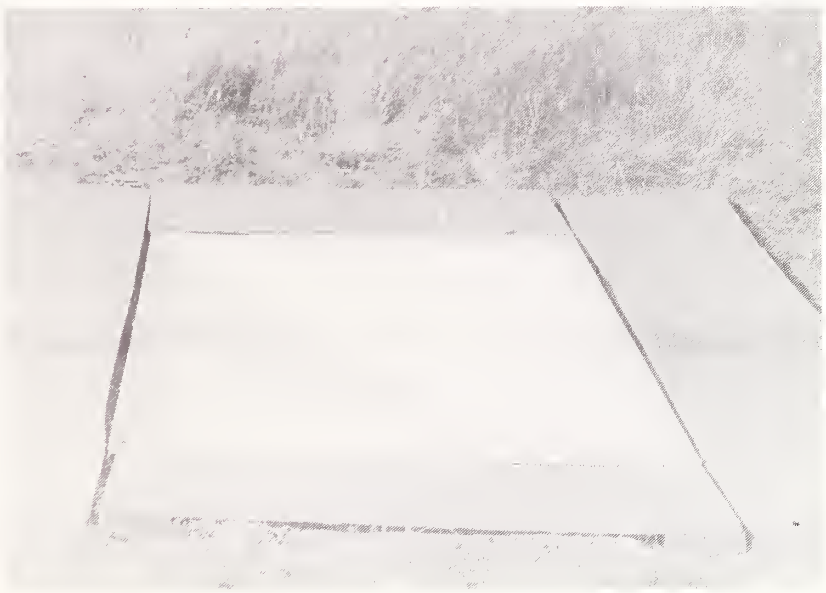

Figure 6b. The collection area of the Pit gage used as a control at the site.

(c)

(d)

Figure 6c-d. c) A wedge type precipitation gage with orifice at 15 in above ground; d) A forestry type precipitation gage with orifice at 15 in above ground.

B. Ecological Systems

Objectives. The broad objective of the program is to develop information which will allow us to predict long term community response to an altered moisture regime. Specific objectives are:

1. To identify the water use efficiency of native vegetation

2. To identify those factors which limit primary productivity

3. To predict changes in community structure which might result from a permanently altered moisture regime

4. To empirically determine water and energy balances for Northern Great Plains grasslands

5. To use inputs from the above to develop a model which will predict the effect which the most probable patterns of increased soil moisture due to weather modification will have on community production, species composition, and stability.

Operations Performed.

1. Thirty-one sites were used for ecological study points. Each site is a fenced square - 24 ft on a side. These sites compose 4 clusters of six sites each, located along a rainfall gradient of ~6.5 to 10 in. seasonal precipitation (May-September). Also one cluster of 7 sites is located within the ERTS dense network in a seasonal rainfall zone of ~8.25 in. Only sites in a high good-to-excellent range condition, as determined by standard soil conservation service techniques, were chosen. This selective measure was to ensure that gross differences in past grazing history would be avoided.

2. Soil surveys have been conducted at each of 25 sites and should be completed on the remaining sites in the spring of 1976. These surveys

will aid in comparing sites of similar soil types among various rainfall zones.

3. Soil moisture was determined gravimetrically, taking samples of the 0-6, 6-12, 12-24, and 24-36 in. layers. These samples were taken during late July and early August (time of peak bio-mass) at 34 ERTS sites, and again in late September at all ecological sites in addition to several of the ERTS sites previously sampled. These measurements enable us to determine both moisture content and moisture distribution within the soil profile.

4. In late September the 24 remaining ecological sites were fenced. Those located at ERTS gage sites had been fenced during May.

5. Production measurements were made at peak bio-mass by clipping to ground level at 34 ERTS sites, selected as being representative of native range. Within each site 5 plots, each uniform within itself, were chosen (Fig. 7), and each was then subdivided into five subplots (Fig. 8). A randomly picked number will designate which subplot is to be clipped each year. The clippings were sorted as to species, air dried, and weighed. Clippings were made because of the exceptionally heavy rainfall received this year. It was felt that clipping for production might give an approximation of what to expect if rainfall were dramatically increased.

6. Basal area measurements were conducted using the line intercept technique at 25 of the ecological sites in mid-August. At each site two permanent lines were established inside and two outside the exclosure. These measurements were made using the mechanical range measurement device as described by Fisser and Van Dyne (1960) (Figs. 9 and 10). All data was coded in the field for entry onto the computer this winter.

Figure 7. An ERTS site with five clipping plots staked out in predominantly Western wheat (<u>Agropyron smithii</u>) vegetation. Each plot is 0.5 m x 1.0 m in size.

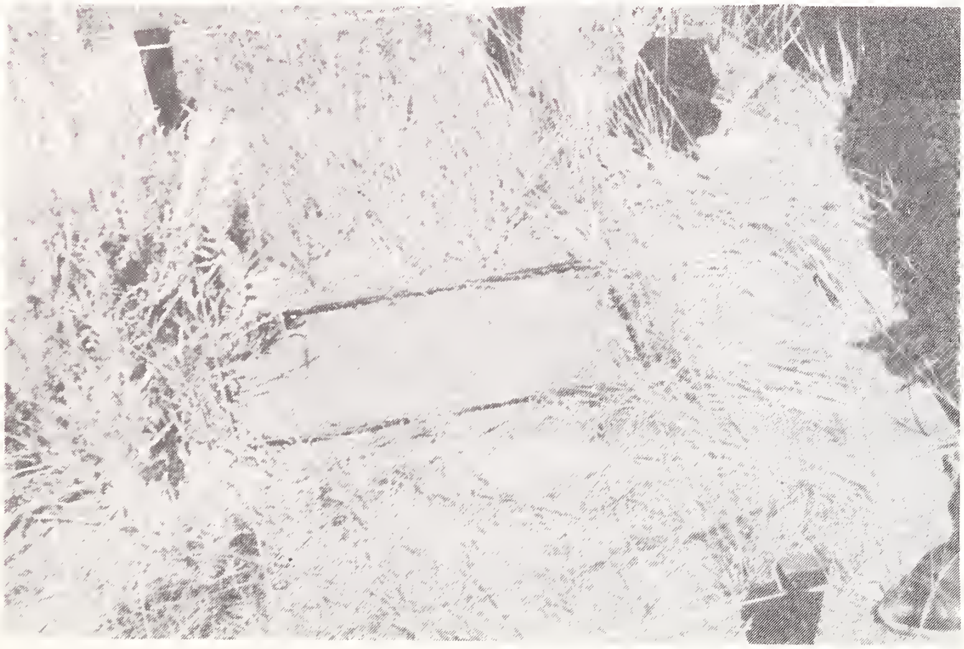

Figure 8. Subplot of 0.2 x 0.5 m after clipping and litter pick up.

Figure 9. Range measurement device used for basal area measurements. The legs fit over steel pins driven into the ground, allowing the same transect line to be monitored each year.

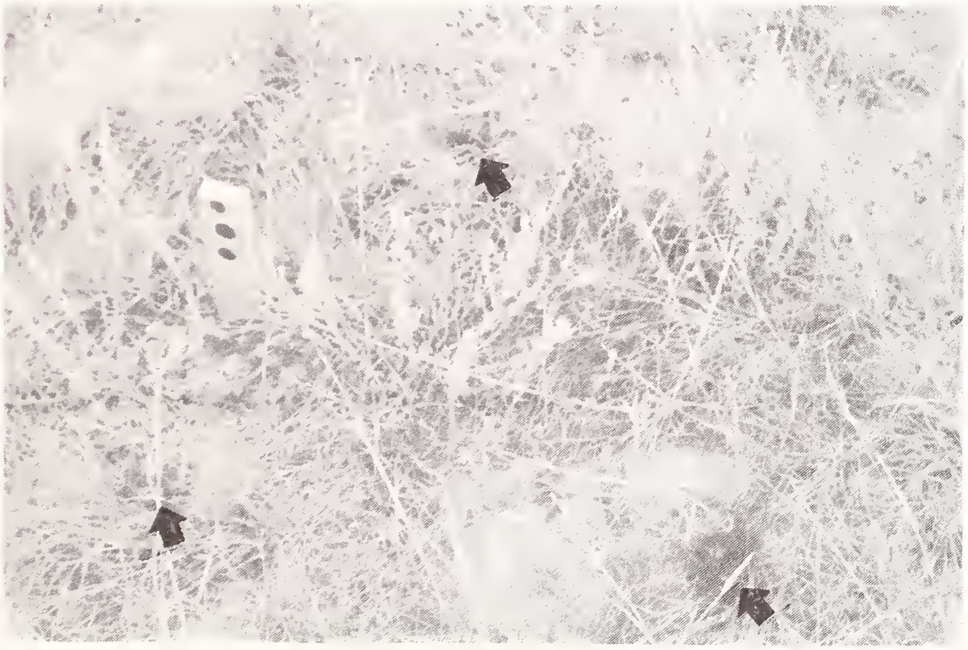

Figure 10. Each transect line was permanently marked by use of $\frac{1}{2}$" rebar driven into the ground. The legs at the "0" end of the device will fit over the pins shown.

Proposed Operations.

1. Raingages will be installed at each ecological study site by the spring of 1976. Total rainfall at these sites will be noted between each site visit.

2. Access tubes for a neutron soil moisture probe are to be installed at each site, one within the exclosure and one outside. This will enable us to monitor soil moisture fluctuations within the soil profile, and also to compare differences from grazed and ungrazed areas. Soil moisture measurements will be taken at the same time the raingages are serviced.

3. Production measurements will be taken using a nondestructive method both inside and outside the exclosure at each ecological study plot if instrumentation of proven field value can be found. With instrumentation it is anticipated to take production measurements at least bi-weekly, by species, in order to correlate the rainfall-soil moisture-plant regime. Without instrumentation production measurements will be by monthly clippings.

4. Basal area measurements will again be conducted beginning in early July at each ecological site. These measurements give an indication of ground cover by species as well as litter composition. Vegetative changes will also be noted at that time.

5. A livestock disease reporting system is being considered, and if developed will be in cooperation with local veterinarians and ranchers. The program should enable us to evaluate the effects of increased (or decreased) precipitation on selected bovine and ovine disease instances, including parasitic diseases.

6. Computer programs designed for storage of ecological data obtained from field measurements will be initiated this winter. These programs will enable us to draw on existing and updated data to aid in correlating rainfall with native range production.

7. We are continuing the effort to seek funds for further experimentation. Examples of research which would be conducted with additional funds are:

a. A sprinkling study on native range, conducted by university scientists within the state. Water would be added to individual study plots as fixed percentages of each natural rainfall.

b. Cooperative studies with the Agricultural Research Service (ARS) in range forage nutrition,

c. and we are discussing with the ARS possibilities of research in the area of water and energy balances.

III. RESULTS AND PROBLEMS

Significant scientific results are not yet available from the 1975 field season. However, a brief summary of accomplishments is appropriate. First, permission for the use of more than 70 meteorological monitoring and 24 ecological monitoring sites was secured. Second, exclosures were constructed around all these sites. Third, assorted meteorological and ecological monitoring equipment were installed and operated throughout the 1975 field season to collect data pertinent to the outlined objectives. Fourth, meteorological and ecological data reduction procedures were formalized and initiated. Continued data reduction and clarification will provide good quality baseline meteorological and ecological data for the period 1 May-1 October 1975 at the primary experimental site.

The only significant problems encountered were those associated with the Radio-Telemetry Network. Many problems occurred as might be expected in the field testing of any new instrumentation system. In particular, several difficulties remain concerning the ability of the Radio-Telemetry Network to operate properly in the field. First, the memory gages were not delivered and no field testing was performed with them. Second, preliminary field tests of the ERTS gages delineated electronic and timing problems in the transmitting and computerization of rainfall data. Third, the ERTS gages were installed too late in the field season to adequately test the effects of insects, animals, plant growth, and other environmental factors. This is especially significant since it was found that vigorous microbial and insect activity was present in and near all the Belfort raingages during the field season.

It appears that the Radio-Telemetry Network needs further testing and refinement before it can be relied upon to provide accurate rainfall data. This means that a proven rainfall collection system for the primary site is mandatory during the 1976 field season.

IV. PUBLICATIONS AND REPORTS

A problem analysis by Dave Perry, on anticipated weather modification effects on native range, has been submitted to the Journal of Range Management. A copy of the draft is enclosed with this report in Appendix I.

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APPENDIX I

D R A F T*

THE EFFECTS OF WEATHER MODIFICATION ON NATIVE RANGE ECOSYSTEMS: A PROBLEM ANALYSIS

Dave Perry

* Revision being done. Article for publication should be somewhat shorter.

THE EFFECTS OF WEATHER MODIFICATION ON NATIVE RANGE ECOSYSTEMS: A PROBLEM ANALYSIS

Dave Perry

I. Introduction

A. Functional Changes

1. Primary productivity

A grassland ecosystem may respond to perturbation by altering both its structure and its function. The most obvious functional change, primary productivity, has been extensively studied in relation to increases in moisture. Regressions of community primary production as a function of precipitation have generally-though not always-yielded significant results, but with varying strength of correlation. Several studies on short grass ranges, composed primarily of blue grama and western wheat grass with secondary grass species either buffalo grass or needle and thread, have found that between 46% and 84% of variations in yields is explained by growing season rainfall (Rogler and Haas, 1947, Smoliak, 1956, Rauzi, 1964, Noller, 1963, Dahl, 1963). However, in a Montana study there was little correlation between precipitation and yields of the community types (Ballard and Ryerson, 1973). Hausli (1972) regressed short grass and little bluestem community production against rainfall in Kansas and found 30 to 36% of variation explained. Thomas and Osenbrug (1959) concluded that seasonal precipitation by itself was not a reliable indicator of bromegrass-crested wheat grass yields, but when precipitation was adjusted by a temperature factor 88% of variation in yield was explained (Thomas and Osenbrug, 1964).

Where positive correlations have been found between rainfall and forage production, precipitation use efficiency estimates have

ranged from approximately 50 lbs. forage/acre-inch water (Thomas and Osenbrug, 1964) to 110 lbs forage/acre inch (Wight and Black, 1972). Wight and Black (1971) estimate that, without fertilization, 500 lbs forage per acre is the maximum increment that can be obtained by addtions of water alone.

Several studies have artifically added water to natural range ecosystems, either by water spreading techniques or sprinkler irrigation.[1] Results are mixed. Two water spreading studies in southeastern Montana resulted in grass forage increases of approximately 300% (Monson and Queensberry, 1958, Branson, 1956). Cosper and Thomas (1961) found yield increases of 16% on a water spreading study in western South Dakota. In New Mexico, water spreading on sandy sites had no effect on vegetative cover (Valentine, 1947).

Klages and Ryerson (1965) added enough water to more than double normal growing season precipitation on a western Montana site, with resultant yield increases of 100-200%. In a study in which soil water stress at 10 cm was kept above -0.8 bars, yield of short grass prairie in Colorado was increased approximately 100% (Lauenroth and Sims, 1973). Smika et all (1965) increased yields of mixed prairie in North Dakota 50% by increasing available water approximately 100%.

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1. Surface modification has also been used extensively to increase soil moisture on rangeland (Wight and Siddoway, 1972, Ryerson et al, 1970, Houston, 1971). However because of highly increased rates of nitrogen release on these areas (Wight and Siddoway, 1972) it is difficult to isolate moisture effects.

At least three sprinkling studies reported in the literature have had little or no effect on primary production. Weaver (1975) found that additions of water ranging from 140% of normal rainfall to constantly-wet increased production of Idaho fescue meadows slightly when water was added in the spring, but not at all for summer additions. Bleak et al (1974) compared yields on Utah grasslands receiving 150% and 67% of normal rainfall, and found no difference. Pettit and Fagan (1974), irrigating buffalo grass in combination with various nitrogen treatments, found lower yields in irrigated than in nonirrigated plots in all but one nitrogen treatment.

Two studies of the effect of irrigation on below ground biomass found no increased root growth as a result of added water (Lauenroth and Sims, 1973, Garwood, 1967). Garwood attributed this to a faster rate of decay of dead roots.

There are a number of possible reasons why research into the dependence of rangeland production on water has produced variable results. Differing experimental parameters, such as distance of sample plots from rain gages, have certainly played a part. Perhaps more important, however, is the reality of natural variation: the interplay, often synergistic, of a complex of biotic and abiotic factors which result in sharp gradients of what is, at any one time or place, the limiting factor. This mosaic of response patterns is molded both by changes in critical environmental factors and differences in the way in which species and communities respond to their environment. The more important contributing factors are discussed below.

Nutrients

Nutrients, especially nitrogen and phosphorus, are commonly in short supply in grasslands (Harmsen and Van Schreve, 1955). Experiments in range fertilization have often failed to produce forage increases because up to 300 lbs/acre of added nitrogen may be tied up in roots, mulch, and microbial cells (Power, 1972). However, when large amounts of nitrogen are added or when small amounts are added in conjunction with irrigation, results are dramatic. Wight and Black (1972) tripled the water use efficiency of short grass range by adding 900 lbs/acre of nitrogen and 100 lbs/acre of phosphorus. On the Pawnee grasslands site in Colorado 50 kg/ha of nitrogen plus irrigation more than doubled yields over an area which was irrigated without added nitrogen (Lauenroth and Sims, 1973). In Western Montana Klages and Ryerson (1965) found that added water increased yields approximately 100%, added nitrogen (100 lbs/acre without water) increased yields 300%, and 100 lbs of nitrogen per acre plus added water increased yields from 500 to 1000%. Lauenroth and Sims (1973), in comparing their findings with those of Klages and Ryerson (1965) suggested that lower evaporation in the Northern Great Plains may result in nitrogen becoming more of a limiting factor than water. White and Moore (1972) postulated that nitrogen was more limiting than water on western South Dakota ranges. Wight and Black (1972) stated that "the most limiting role of water in the energy fixing processes of a rangeland ecosystem is its effect on nutrient cycling."

The effect ~~which~~ that added precipitation has on nutrient cycling rates is directly related to its effect on microbial activity. Various laboratory experiments have shown that soil CO_2 evolution

and/or nitrification is inhibited at 0 bars moisture stress, rises quickly at -.15 to -.50 bars and then declines with further drying, although the decline may be slow and significant, activity may continue at tensions as low as -15 bars (Parker and Larson, 1962, Justice and Smith, 1962, Miller and Johnson, 1964, Wiant, 1967, Nyhan and Doxtader, 1974). Koepf (1952) reported that the optimum moisture content for the activity of soil bacteria was 60-70% of field capacity.

If microbial activity is largely confined to certain moisture tension ranges, nutrient release should be correlated with the amount of time which soil moisture tension is within this range, and therefore to the pattern rather than simply the amount of rainfall. This is supported by Soulides and Allison's (1961) observations that decomposition rate was significantly increased by alternate wetting and drying of the soil. DeJong et al (1974) found that the number of wetting and drying cycles in the soil was responsible for a large part of the annual variation in soil respiration. Wildung et al (1973) found soil respiration rate highly correlated with soil moisture and temperature in one year, but not at all in the next. They suggested that differences in rainfall pattern between the two years might be an explanation. However, "few experiments have been designed to determine the influence of fluctuating soil water on microbial activity" (Nyhan and Doxtader, 1974).

Rainfall Pattern

The effect of timing, frequency, and amount of rainfall from single storms has generally been neglected in range research

(c.f. Smith, 1972), although these factors have been acknowledged as important in water use efficiency (Wight and Black, 1974), nutritive levels of grass (Rogler and Haas, 1947), community composition (Albertson and Tomanek, 1965), phenological events (Sundberg, 1974, Beatley, 1974), and insect response (Cooper and Jolly, 1969). Several authors have suggested that differing patterns of rainfall from year to year may explain the poor correlations which are often found between primary productivity and rainfall (Wight and Black, 1974, Ballard and Ryerson, 1973).

One of the most important aspects of rainfall pattern is its possible effect on community composition, which will be discussed in more detail later.

Genetic Limitations

There is evidence that genetic factors play an important role in the ability of a grassland to respond to improved moisture or nutrient supplies. Wight and Black (1974) found that mixed prairie biomass in Eastern Montana peaked in mid-July regardless of the amount of soil moisture available at that time. They concluded that peak standing crop was genetically controleed and that maximum possible water use by this type of community was about 25 cm. Weaver (1975) suggested that genetic control of the growing period may have been a factor in the failure of Idaho fescue meadows to respond to summer irrigation. Laude (1953) studied the dormancy behavior of twenty grass species. Of these, seven species ceased growth in midsummer even when kept continuously wet.

Bradshaw et al (1960, 1964) found that species from nutrient-poor, low productivity communities responded little to added nutrients.

They postulated that low yields may have a selective advantage in nutrient poor situations.

2. Secondary Productivity

It is difficult to generalize concerning consumer response to an ecosystem perturbation. Among arthropods it is dependent on trophic level and successional status of the community (Hurd and Wolf, 1974). There is significant variation in the response of closely associated grasshopper populations to moisture, temperature, and starvation (Hastings and Pepper, 1974), and there are year to year fluctuations in grasshopper populations "which are not the direct result of vegetational changes along, nor probably of any single environmental factor" (Anderson, 1964). However, Edwards (1960) did find a weak relationship between grasshopper numbers in Saskatchewan and April-August precipitation in the preceding two years. Riegert (1963) argues that rises in grasshopper infestations in Saskatchewan have been at least partly due to warm, dry weather during the growing season, whereas cool, moist conditions caused population declines.

Cooper and Jolly (1969) suggest that there would be no major insect pest outbreaks as a result of weather modification. Data from irrigated and ferilized range plots in Colorado show insect biomass increases which are generally consistent with increases in forage production (Lavigne and Kumov, 1974).

As in the case of grasshoppers, unexplained fluctuations in the populations of small mammals make correlation of their numbers with weather variables very difficult. Okulora and Myskin (1974) found that numbers of the northern red-backed mole (Clethrionomys nutilus) correlated principally with temperature, however, there was an inverse

correlation with spring precipitation. Lauenroth and Sims (1973) found shifts in species composition coupled with significantly smaller biomass in plots which had been irrigated for two years.

The response of large herbivores to changes in primary productivity can be generalized fairly accuragely from cattle response. Ballard and Ryerson (1973) found that in southeast Montana calf weights were significantly correlated to growing season and previous year precipitation, but gain of wet cows was not. In a higher rainfall zone in central Montana there was no relation between precipitation and cattle weight gains. In a North Dakota study it was found that weaning weights of calves were lowest for years which received the greatest amounts of rainfall from April through July (Johnson et al, 1974).

The effect of increased forage on cattle weights will depend largely on the nutritive value of the added forage. The effects of increased moisture on the protein content of grasses is quite variable. In many parts of Montana optimum nutritive value is reached at precipitation levels slightly under average (Payne, 1975). Willard and Schuster found that crude protein was highest when rainfall was adequate. Wight and Black (1974) reported that nitrogen concentration in above ground biomass was not dependent on moisture, but Thomas and Osenbrug (1964) found that the nitrogen content of fertilized grasses was diluted by added water.

The relationship between nutrient content of grasses and precipitation is probably dependent on a number of factors, including grass species and timing of the rainfall. Crude protein percent goes up in blue grama following a summer thunder storm, but not in western wheat grass (Rauzi et al, 1969).

B. Structural Changes

1. Species change

Whittaker and Woodwell (1972) suggested that structural changes may be a community mechanism whereby functional changes are minimized. This principle is manifested in the highly variable environment of the Great Plains grassland through inter and intraspecific variability, which act to produce a fairly constant community response to the environment (except in cases of extreme perturbation), although changes within the community may be quite dynamic. With respect to rainfall variations this is less true in the southern Great Plains, where response to varying precipitation usually takes the form of changes in basal area. However, in the north, community composition changes with the weather, both through changes in the ratios of the dominants and movement of species into and out of the community (Coupland, 1959).

The exact nature of changes in community composition due to increased precipitation will depend on timing of the rainfall, its effect on nutrient cycling, and the way in which the various species (or genotypes) in a particular community respond to these factors. Spring rains will probably favor the development of cool season over warm season grasses (Ballard and Ryerson, 1973), while summer rains will do the opposite (Klages and Ryerson, 1965). Because of its ability to respond to favorable growing conditions at any time of year (Turner and Klipple, 1952) blue grama might be expected to gain especially from rains which occur during the dormant period of other grasses. Forb production also appears to be relatively favored by late summer and fall rains (Noller, 1963).

Grasses vary considerably in their ability to respond to moisture,

and therefore some species will gain relatively more than others from added rainfall. For example, in Kansas Shiflet and Dietz (1974) found fairly good correlations between rainfall and the production of big bluestem, but no correlation for Indian grass and switch grass, and a slight negative correlation for little bluestem.

Coupland (1959) studied the effect of a period of unusually favorable weather on grasslands in southern Saskatchewan and Alberta. Percent composition contributed by wheat grasses and *Stipa spartea* increased markedly, while blue grama and needle and thread grass decreased. *Stipa spartea* apparently actively invaded sites which had formerly been too dry.

Pitting and scalping studies in northern Montana have resulted in shifts of dominance from needle and thread grass to western wheatgrass. They have also resulted in some cases in marked increase in fringed sagewort, and in the appearance of grasses, such as squirrel tail ( ), not formerly present (Ryerson et al, 1970). Fifteen years after the initiation of these treatments species change is still dynamic. For example, fringed sagewort now appears to be decreasing (Houlton, 1975).

In Colorado sprinkling native range resulted in increase in warm season and decreases in cool season species. The biomass of warm season grasses peaked earlier as well as being higher, while fluctuations in the yield of cool season grasses and forbs were greatly increased (Lauenroth and Sims, 1973).

The effect of increased rainfall on nutrient availability will perhaps be more important than moisture in determining species change. Lunt (1972) points out that there is "a considerable body of opinion

that nitrogen is a major ecological factor determining the distribution of species." He further speculates that relatively modest differences in interspecific response to factors such as phosphorus may exert "powerful effects on population distributions in competitive communities."

Fertilizer experiments in the Northern Plains have generally resulted in increases in western wheatgrass and decreases in blue grama (Wight and Black, 1972, Lorenz, 1970, Rogler and Lorenz, 1957). In general, cool season grasses respond to nitrogen better than warm season grasses (Williams, 1953). There is also a tendency for non-grass species to increase relative to grass with fertilization (Cosper and Thomas, 1961, Goetz, 1969).

Phosphorus supply has also been shown to be an important factor affecting the species composition of grasslands (t'Harte, 1949, Sonnevald et al, 1959, Bradshaw et al, 1960).

Genotypic Change

It seems not only conceivable but probable that an altered moisture-nutrient regime would result in genetic change within populations on a particular site. Experiments have demonstrated that such change can occur very rapidly (Levins, 1968),and a recent paper has linked moisture availability to incorporation of phosphorus into nucleic acids of the desert plant *Anastatica hierochuntica L.* (Harung, 1974), providing a possible mechanism for water-linked genetic change.

Very little is known concerning ecotypic variation of grasses with respect to water and nutrient requirements. Genotypic

differences in water requirement have been shown in orchard grass (Keller, 1953) and pubescent and intermediate wheatgrass (Baker and Hunt, 1961), and differential response to magnesium and calcium has been found among populations of bluebunch wheatgrass (Main, 1974). However, the extent of such differentiation in nature remains to be determined. Knowledge of this will be important in determining genetic change which might occur on a particular site.

C. Other Potential Effects

1. Community Stability

The question of stability is directly related to the degree of success which weather modification operations have. If rain is increased during normally wet years and not affected during drought the result will be an increase in the amplitude of climatic variation. What this means in an already highly variable environment is not known. If periods of favorable weather result in dominance by more mesic species or genotypes the ability of the community to respond successfully to drought will involve a much higher compositional flux than at present. Effects of a drought could be more severe, recovery could take longer.

The experiment of Klages and Ryerson (1965) demonstrates quite clearly problems which may be encountered. They added water and nitrogen to native range in 1958, 1959, and 1960 with significant increases in yield. Nineteen hundred and sixty and 1961 were drought years, and by 1962 grasses in previously fertilized and watered plots had decreased much more than in control plots. Needle and thread grass was virtually eliminated from experimental plots, while forbs increased.

Apparently three years of exceptionally favorable growing conditions had reduced these communities' ability to withstand unfavorable conditions.

2. Saline Seep

Few range scientists believe that a saline seep problem could develop from increased precipitation on rangeland. However, there are indications, yet to be verified, that ground water levels are rising beneath scalped and pitted areas and beneath some rest-rotation pastures in northern Montana (Ryerson, 1975). It is a situation that must be monitored very carefully.

3. Pathogens

Plant Virus Diseases

Broadbent (1967) reviewed the research on the influence of weather on plant virus diseases, and concluded that it is "considerable and very complex (and) has been adequately studied in relation to very few diseases. . . . ."

Aphids and leafhoppers are the principal vectors of plant diseases. Aphids multiply faster in warm dry summers than in cool, moist ones, however, in dry areas, wet periods which favor the growth of plants may also favor the proliferation of the insects that feed on them (Broadbent, 1967). Curly top virus of beet is increased by spring rains because of increased germination of annual weeds which harbor the virus (Severin, 1939), and, in California, rain encourages the growth and subsequent infestation of grasses by aphids which carry cereal yellow dwarf virus (Oswald and Houston, 1953).

Temperature effects on aphids and leafhoppers are mixed. In

general, warm temperatures increase aphid movement and thus infection rates (Bald, Norris, and Helson, 1950), however, very warm temperatures may result in a cessation of aphid activity altogether (van der Plank, 1944). Hot weather may either increase or decrease the infectivity of leafhoppers, depending on species (Kunkel, 1937, Webb, 1956).

Parasites

The Liver Fluke is an important parasite of cattle and sheep in many areas. Two conditions are necessary for survival and spread of flukes: (1) an adequate population of the snail *Lynnaea truncatula*, which is an essential host during a portion of the fluke's life cycle, and (2) saturated soil for movement of the fluke from host to host (Ollerenshaw, 1967). A concern has been voiced that enhanced rainfall may increase that incidence of liver fluke disease in the northern Great Plains (now virtually nonexistent). However, Ollerenshaw (1967) has determined that, in England, three consecutive months in which rainfall exceeds evaporation are necessary for the fluke to complete its life cycle. In addition, areas of standing water are necessary for suitable snail habitat. It seems unlikely that weather modification in the semi-arid Great Plains will be successful enough to fulfill either of these conditions.

4. Runoff

The amount of runoff produced by increased rainfall will be dependent on soil type, vegetative cover, and the way in which storm intensity is affected by precipitation modification. On mixed prairie, grassland condition exerts a greater control over infiltration than soil type. On semi-arid sites, because of sparse vegetation, the opposite is true (Wolf, 1970).

On lightly grazed areas in the vicinity of Miles City, Montana, infiltration rate was found to be 4.3 in/hr on sandy loam - sandy clay sites, 4.8 in/hr on clay, and 6.7 in/hr on silt clay (Reed and Peterson, 1961). However, on silt loam sites in McCone County, Montana, in high range condition, only 1.4 in/hr was infiltered (Rauzi, 1960).

Wolf (1970) reported that the average one hour duration storm was capable of being infiltered on practically all range sites which he studied. The average ten minute duration storm could be infiltered where range conditions were good to excellent, but not when they were fair to poor. Branson and Owen (1970) found that 74% of the variation is runoff from watersheds underlain by Mancos shale was explained by the proportion of bare soil in the watershed.

The above data indicates that in the short run, runoff in semi-arid areas may be increased by precipitation enhancement. However, if increased rainfall results in increased vegetative cover, runoff will decrease proportionately and the long term effect will be beneficial.

Summary of Potential Effects

1. Over the short term above ground primary production will be increased slightly in most areas, but without fertilization maximum yields per inch of added rainfall will probably not exceed 50-110 lbs/acre, with a maximum increment of 500 lbs/acre.

2. The long term effect of added water on primary production will depend on the degree to which decomposition rates are increased, and therefore the rate at which nutrients are released. Hitrogen is probably the major limiting factor to forage growth in the Northern Great Plains.

3. Increased forage production in the absence of increased nitrogen may have a neutral or negative effect on livestock weight gains.

4. Changes in consumer populations will probably not be dramatic, although small mammal numbers may decline. The effect such a decline would have on community function is not known.

5. Compositional changes will almost certainly occur in the community, the exact nature of which will be highly dependent on the pattern of rainfall increases. Enhanced precipitation in the spring (April and May) will probably result in increased proportions of more mesic, high producing species, while summer and fall rains will effect mainly warm season grassland forbs.

6. Cool, moist weather during the growing season could result in declines in grasshopper populations.

7. Enhancement of precipiation could result in communities which are less able to withstand adverse conditions. If drought periods cannot be affected by weather modification, more extreme fluctuations in the vegetation may result.

8. Runoff will be reduced in an amount proportionate to increased vegetative cover, providing there isn't a significant increase in storm intensity.

9. There will be both positive and negative effects on virus diseases of plants. The net effect cannot be predicted.

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